tr joelPCM Academic Council

DEPARTMENT OF NATURAL SCIENCES · ADVANCED BIOLOGY

Advanced Biology — Paper 1: Theory | Set IV

Scenario-Based Assessment · Question Paper Only

Duration: 3 Hours | Total Marks: 80 | Items to Attempt: 4 of 6 | Code: BIO/P1/SET-IV/2025

INSTRUCTIONS TO CANDIDATES

1. This paper consists of Section A (compulsory) and Section B (choice).
2. In Section A, attempt BOTH Items 1 and 2.
3. In Section B — Part I, attempt ONE item from Items 3 and 4.
4. In Section B — Part II, attempt ONE item from Items 5 and 6.
5. Each item carries 20 marks. Total = 80 marks.
6. Write in complete, well-structured sentences unless otherwise directed.
7. Annotated biological diagrams and labelled equations may be used to support answers.
8. Begin each item on a fresh page of your answer booklet.

SECTION A — COMPULSORY

Attempt ALL items in this section | 40 marks

ITEM 1

AO1 · Cell Division, Cell Cycle Regulation, Cancer Biology & Molecular Diagnostics

AO1 **20 marks**

The **Uganda Cancer Institute (UCI)** in Mulago, Kampala, is the country's only specialised cancer treatment and research centre. Oncologists at UCI have observed a sharp rise in **colorectal cancer (CRC)** diagnoses, particularly among adults aged 35–60 in urban Kampala, attributed to dietary changes, sedentary lifestyles, and reduced fibre intake. A research team conducted a histological and molecular study comparing biopsy samples from **normal colonic mucosa**, **pre-cancerous adenomatous polyps**, and **invasive colorectal carcinoma** tissue in 240 consenting patients.

Histological cell counts, cell cycle protein expressions, and molecular markers were quantified from standardised biopsy sections. Data are presented in the table below.

Table 1: Cell cycle and molecular parameters across normal colonic mucosa, adenomatous polyp, and invasive colorectal carcinoma tissue — Uganda Cancer Institute, 2024

Parameter	Normal Colonic Mucosa	Adenomatous Polyp	Invasive Colorectal Carcinoma
Mitotic index (% cells in mitosis)	0.8	4.2	18.6
Cells in G1 phase (% of total)	72	54	28

Cells in S phase (% of total)	14	24	41
p53 tumour suppressor protein (% of normal expression)	100	48	6
Cyclin D1 expression (% of normal)	100	218	486
Ki-67 proliferation marker (% positive cells)	8	34	82
Telomerase activity (U/µg protein)	0.2	1.8	14.6
E-cadherin expression (% of normal)	100	74	12
Matrix metalloproteinase-9 / MMP-9 (ng/mL)	4.1	18.3	86.4

> *You are an oncologist and cell biologist at the Uganda Cancer Institute, presenting findings to the UCI Research and Training Committee to guide early detection and prevention strategies for colorectal cancer in Kampala.*

TASK

(a) Using your knowledge of the cell cycle, mitosis, and molecular mechanisms of tumour suppression, explain the progressive molecular and cellular changes observed from normal mucosa through adenomatous polyp to invasive carcinoma, accounting for the roles of p53, Cyclin D1, telomerase, E-cadherin, and MMP-9 in cancer development and invasion. **[12 marks]**

(b) Recommend and justify a science-based colorectal cancer early detection and prevention programme for Kampala, drawing on the molecular markers identified in this study and the known dietary and lifestyle risk factors in urban Uganda. **[8 marks]**

ITEM 2

AO2 · Mineral Nutrition, Nitrogen Cycling, Soil Biology & Sustainable Agriculture

AO2 **20 marks**

Ntungamo district in south-western Uganda is a major producer of Irish potatoes, beans, and sorghum. Soil degradation driven by intensive cultivation, overuse of synthetic nitrogen fertilisers, and loss of organic matter has caused declining yields on smallholder farms over the past decade. The **National Agricultural Research Organisation (NARO)** established a long-term soil fertility trial at Ntungamo Research Station comparing four soil management systems: **continuous synthetic fertiliser (CSF)**, **integrated soil fertility management (ISFM)** combining mineral fertiliser with compost, **legume intercropping (LI)**, and a **no-input control (NI)**. Soil biological, chemical, and crop yield parameters were measured after five years of continuous treatment application.

Key soil and crop parameters after five years of the NARO Ntungamo Soil Fertility Trial are presented in the table below.

Table 2: Soil chemistry, biology, and crop yield parameters after five years — NARO Ntungamo Soil Fertility Trial

Parameter	No-Input Control (NI)	Continuous Synthetic Fertiliser (CSF)	Legume Intercropping (LI)	Integrated Soil Fertility Management (ISFM)
Soil organic carbon (% dry weight)	1.2	1.1	1.8	2.4
Total soil nitrogen (mg/kg)	480	620	940	1,240
Rhizobium nodule count (per plant root system)	0	0	62	48
Soil microbial biomass (µg C/g soil)	142	118	286	412
pH	5.4	4.8	5.8	6.1
Nitrification rate (µg NO3-N/g soil/day)	0.8	2.4	3.6	4.8
Available phosphorus (mg/kg)	4.2	6.8	7.4	12.6
Irish potato yield (t/ha)	6.2	14.8	11.4	18.6
Bean yield (t/ha)	0.8	1.2	1.9	2.4

You are a soil scientist and agronomist at NARO, presenting trial findings to district agricultural officers in Ntungamo and advising smallholder farmers on the most sustainable and productive soil management approach.

TASK

(a) Account for the differences in soil nitrogen content, microbial biomass, soil pH, and crop yield observed across the four management systems, making specific reference to the nitrogen cycle processes of nitrogen fixation, nitrification, denitrification, and

ammonification, and explaining the role of soil microorganisms and organic matter in maintaining soil fertility. **[12 marks]**

(b) Propose and justify an integrated soil management strategy for smallholder farmers in Ntungamo that maximises long-term crop productivity and soil health, with reference to the biological, chemical, and agronomic evidence from the trial data. **[8 marks]**

SECTION B — CHOICE

Attempt ONE item from each Part | 40 marks

PART I — AO3: Analysis of Animal Systems and Behaviours

Attempt ONE item (Item 3 or Item 4)

ITEM 3

AO3 · Digestion, Nutrient Absorption, Malnutrition & Clinical Nutrition

AO3 **20 marks**

Kaabong District Hospital in Karamoja, north-eastern Uganda, manages one of Uganda's highest rates of childhood acute malnutrition. During the 2023 lean season, the hospital admitted 312 children under five years of age with **severe acute malnutrition (SAM)**. A clinical nutrition team categorised admitted children into three groups based on their presentation: **marasmus** (severe energy-protein deficiency), **kwashiorkor** (predominantly protein deficiency with adequate energy intake), and a **moderately malnourished control group** receiving standard supplementary feeding. Biochemical and digestive function assessments were conducted on admission and after eight weeks of nutritional rehabilitation.

Admission and post-rehabilitation data for the three groups are presented in the table below.

Table 3: Nutritional, biochemical, and digestive parameters on admission and after 8-week rehabilitation — Kaabong District Hospital, 2023

Parameter	Moderately Malnourished (Control)	Marasmus	Kwashiorkor
Weight-for-height z-score (WHZ) on admission	-2.1	-3.8	-2.6
Serum albumin on admission (g/L)	28	22	9
Serum albumin after 8 weeks (g/L)	34	36	28
Oedema (fluid accumulation)	Absent	Absent	Generalised
Pancreatic amylase activity (U/L)	180	62	44
Intestinal lactase activity (% of normal)	80	28	22
Serum zinc (µmol/L)	10.2	6.4	4.1
Villus height in jejunum (µm)	420	210	180
Absorptive surface area (% of normal)	100	48	40
Catch-up weight gain after 8 weeks (g/week)	80	148	62

You are a consultant paediatrician and clinical nutritionist at Kaabong District Hospital, responsible for developing evidence-based rehabilitation protocols and presenting findings to the district health team and Ministry of Health nutrition programme.

TASK

(a) Explain the biochemical and physiological mechanisms responsible for the differences in oedema, serum albumin, digestive enzyme activity, villus morphology, and nutrient absorption observed between the marasmus and kwashiorkor groups, with reference to the roles of protein metabolism, osmotic pressure, enzyme synthesis, and intestinal cell renewal. **[12 marks]**

(b) Propose and justify a staged nutritional rehabilitation protocol for the kwashiorkor group at Kaabong Hospital, explaining the physiological basis for each stage and addressing the specific metabolic risks associated with refeeding severely malnourished children. **[8 marks]**

ITEM 4

AO3 · Reproductive Physiology, Hormonal Regulation & Fertility Management

AO3 **20 marks**

Kawolo General Hospital in Buikwe district serves a large rural population in which **infertility** and unintended pregnancy are both significant public health challenges. The hospital's reproductive health unit conducted a study comparing hormonal and physiological profiles across four groups of women aged 20–35 years: **normal ovulatory cycle (control)**, **polycystic ovary syndrome (PCOS)**, **hypothalamic amenorrhoea (HA)** (cessation of menstruation due to low body weight/stress — common in female Karamoja IDP camp residents), and women using **combined oral contraceptive pill (COCP)**.

Hormonal assays and reproductive parameters collected across the menstrual cycle for each group are presented below.

Table 4: Reproductive hormonal and physiological parameters across four groups — Kawolo General Hospital Reproductive Health Unit

Parameter	Normal Ovulatory Cycle	PCOS	Hypothalamic Amenorrhoea (HA)	Combined Users
FSH (IU/L, early follicular phase)	6.8	4.2	1.8	0.6
LH (IU/L, early follicular phase)	5.4	18.6	1.4	0.4
LH:FSH ratio	0.8	4.4	0.8	0.7
Oestrogen / E2 (pmol/L, mid-cycle peak)	820	340	110	180
Progesterone (nmol/L, mid-luteal phase)	28.4	4.2	1.6	2.1
Testosterone (nmol/L)	1.4	4.8	0.6	0.9
Antral follicle count (AFC, per ovary)	8	24	3	5
Ovulation confirmed (%)	100	18	0	0
Endometrial thickness at ovulation (mm)	10.2	6.4	3.1	3.8

You are a reproductive endocrinologist and gynaecologist at Kawolo Hospital, advising the reproductive health unit on the hormonal basis of each condition and developing management protocols appropriate for the hospital's rural setting and resource constraints.

TASK

(a) Explain the hormonal and physiological mechanisms responsible for the disruption of ovulation in PCOS, hypothalamic amenorrhoea, and COCP users, accounting for the differences in FSH, LH, LH:FSH ratio, oestrogen, progesterone, testosterone, antral follicle count, and endometrial thickness observed across the four groups, with reference to the hypothalamic-pituitary-gonadal (HPG) axis and feedback mechanisms. **[12 marks]**

(b) Propose evidence-based, resource-appropriate management strategies for women with PCOS and hypothalamic amenorrhoea at Kawolo Hospital, justifying each

recommendation with reference to the specific hormonal abnormalities identified in the data. **[8 marks]**

ITEM 5

AO4 · Aquatic Ecosystem Ecology, Eutrophication & Environmental Management

AO4 **20 marks**

Lake Bisina, located in Pallisa district, eastern Uganda, is a shallow freshwater Ramsar wetland supporting subsistence fishing communities and rich waterbird biodiversity, including the globally threatened **shoebill stork** (*Balaeniceps rex*). Since 2005, rice irrigation schemes, cattle grazing at lake margins, and growth of Pallisa town have accelerated nutrient loading into the lake. The **Directorate of Water Resources Management (DWRM)** established a monitoring programme with quarterly sampling of water quality, biological indicators, and biodiversity metrics. A decade of monitoring data are summarised below.

DWRM Lake Bisina monitoring data from 2005 to 2024 are presented in the table below.

Table 5: Water quality, biological, and biodiversity parameters — DWRM Lake Bisina Monitoring Programme, 2005–2024

Parameter	2005	2010	2015	2020	2024
Total phosphorus (µg/L)	18	42	86	148	210
Total nitrogen (µg/L)	320	580	1,040	1,840	2,640
Chlorophyll-a / phytoplankton biomass (µg/L)	8	22	58	112	186
Secchi depth / water clarity (m)	1.8	1.2	0.6	0.3	0.2
Dissolved oxygen — bottom waters (mg/L)	7.2	5.8	3.4	1.6	0.8
Cyanobacteria dominance (% of phytoplankton)	4	12	38	72	88
Fish species richness (no. of species)	28	24	18	11	8
Waterbird species recorded	42	38	29	19	14
Shoebill stork nesting pairs	12	10	6	3	1

You are a limnologist and wetland ecologist serving on the DWRM Lake Bisina Technical Committee, preparing a restoration action plan for submission to the National Environment Management Authority (NEMA) and the Ramsar Secretariat.

TASK

(a) Analyse the process of eutrophication in Lake Bisina, using evidence from the monitoring data to explain the cascade of ecological changes from nutrient loading through phytoplankton bloom development, oxygen depletion, and biodiversity loss, with

reference to the roles of phosphorus and nitrogen cycling, decomposer activity, and competitive displacement of species. **[12 marks]**

(b) Propose and justify a comprehensive restoration and protection plan for Lake Bisina that addresses both the nutrient sources driving eutrophication and the recovery of biodiversity and ecosystem services, with reference to specific ecological and management mechanisms. **[8 marks]**

ITEM 6

AO4 · Gene Technology, Genetic Modification, Biosafety & Agricultural Biotechnology

AO4 **20 marks**

The **National Cotton Research Programme (NCRP)** at Serere Agricultural and Animal Production Research Institute (SAARI) in Soroti district has been evaluating **Bt cotton** (*Gossypium hirsutum* transformed with the **Cry1Ac gene** from *Bacillus thuringiensis*) as a potential solution to bollworm (*Helicoverpa armigera*) infestations that cause up to 40% crop losses in Uganda's cotton belt. The programme conducted a five-year field trial at SAARI comparing Bt cotton with conventional cotton varieties under identical agronomic management. Molecular, agronomic, and ecological data were collected annually.

Five-year mean data from the SAARI Bt cotton field trial are presented in the table below.

Table 6: Molecular, agronomic, and ecological parameters — SAARI Bt Cotton Field Trial, Soroti (5-year mean, 2019–2024)

Parameter	Conventional Cotton (non-Bt)	Bt Cotton (Cry1Ac)
Cry1Ac protein expression in leaves (µg/g fresh weight)	0	18.4
Bollworm larval survival on leaf tissue (%)	84	6
Insecticide spray applications per season (no.)	8.2	1.4
Seed cotton yield (kg/ha)	980	1,640
Yield loss attributed to bollworm (%)	38	4
Non-target insect diversity index (Shannon H')	2.14	1.98
Soil Bacillus thuringiensis spore count (spores/g soil)	12	18
Resistance allele frequency in bollworm population	0.02	0.08
Farmer pesticide cost (UGX/season, × 10^3)	320	48
Gross margin above variable costs (UGX/ha, × 10^3)	1,240	2,860

You are a molecular biologist and agricultural biotechnologist at SAARI, presenting the Bt cotton trial findings to the Uganda Biosafety Committee (UBC) and the Parliamentary Committee on Agriculture to inform a decision on commercial release approval.

TASK

(a) Explain the molecular mechanism by which the Cry1Ac protein confers resistance to bollworm in Bt cotton, account for the agronomic and ecological data observed in the trial including the changes in non-target insect diversity, soil Bacillus spore counts, and resistance allele frequency in the bollworm population, and evaluate the significance of these findings for long-term Bt cotton deployment in Uganda. **[12 marks]**

(b) Evaluate the biosafety, ecological, and socioeconomic considerations that the Uganda Biosafety Committee should weigh in deciding whether to approve commercial release of Bt cotton in Uganda, and propose a risk management framework that would allow safe and equitable deployment of this technology for smallholder cotton farmers. **[8 marks]**